0.5 times the velocity head. The pressure loss in elbows must also be allowed for in the design.

FRICTION LOSSES

Friction loss in *straight* ducts is most readily calculated by means of the Air Friction Chart, Fig. 2, which was developed by recent research at the A.S.H.V.E. Research Laboratory [2]. This chart is constructed from the basic flow equation:

$$h_f = f \frac{l}{D} \frac{V^2}{2g} \tag{3}$$

where

h_f = head loss due to friction, in feet of fluid flowing.
l = length of conduit, feet.
D = inside diameter of conduit, feet.
V = fluid velocity, feet per second.
g = acceleration due to gravity, 32.17 fps per second.
f = a non-dimensional friction coefficient which, for ventilation work depends upon Reynolds Number and the relative roughness of the conduit. Appropriate values of f were taken from the work of Moody [3].

The air friction chart is based on standard air at 29.921 in. of mercury barometer and 70 F, flowing through average clean round galvanized metal ducts having approximately 40 joints per 100 ft. For the average application, it should prove sufficiently accurate, without corrections, for any air temperature from 50 F to 90 F, for any relative humidity, and for any normal variation in barometric pressure. For widely varying air pressures or temperatures or for unusual duct conditions, the friction values obtained from the chart should be corrected. If precise results are desired, corrections should be made by use of Equation 3, with the appropriate value of the coefficient of friction, f. However, the following approximate equations [2] are presented and will be found sufficiently accurate for most purposes.

For perfectly smooth ducts: $$h_o = h_s \left(\frac{\rho_o}{\rho_s}\right)^{0.81} \left(\frac{\mu_o}{\mu_s}\right)^{0.19} \tag{4}$$

For average ducts, $$h_o = h_s \left(\frac{\rho_o}{\rho_s}\right)^{0.90} \left(\frac{\mu_o}{\mu_s}\right)^{0.1} \tag{5}$$

For very rough ducts, $$h_o = h_s \left(\frac{\rho_o}{\rho_s}\right) \tag{6}$$

where

h = friction loss.
ρ = density.
μ = absolute viscosity.

h, ρ and μ may be in *any consistent units*. *Subscripts* o and s refer to *actual operating* and *standard* conditions respectively.

The absolute viscosity of dry air at various temperatures is given in Fig. 3. The effect of relative humidity on viscosity may be neglected.

Example 1. Assume that it is desired to circulate 10,000 cfm of air through 75 ft of 24 in. diameter pipe. Find 10,000 cfm on the left scale of Fig. 2 and move horizontally right to the diagonal line marked 24 in. The other intersecting diagonal shows that the velocity in the pipe is 3200 fpm. Directly below the intersection it is found that the friction per 100 ft is 0.50 in.; then for 75 ft the friction will be 0.75 × 0.50 = 0.38 in. In a like manner any two variables may be determined by the intersection of the lines representing the other two variables.

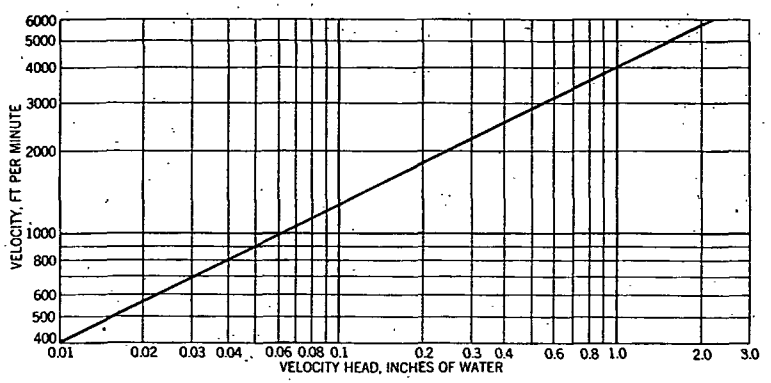

FIG. 1. RELATION BETWEEN VELOCITY AND VELOCITY HEAD FOR DRY AIR

Circular Equivalents of Rectangular Ducts

An air handling system is usually sized first for round ducts and, if rectangular ducts are desired, their sizes are selected to provide air carrying capacities equivalent to those of the round ducts originally selected. Table 1 gives directly the rectangular duct sizes equivalent to each size of circular duct in friction and capacity. The values in this table were obtained from the equation:

$$d = 1.265 \sqrt[5]{\frac{(a\,b)^3}{a+b}} \tag{7}$$

where

a = one side of rectangular duct feet or inches.
b = other side of rectangular duct, feet or inches.
d = equivalent diameter of round pipe for equal friction per foot of length to carry the same capacity, feet or inches.

Rectangular equivalents of round ducts are also given in the curves of Fig. 4 which are plotted from data based on Equation 7. To use the chart, locate the diagonal curve giving the diameter of the round duct. The width and height of an equivalent rectangular or square duct may then be read as the abscissa and the ordinate of any point on the curve.

Multiplying or dividing the length of each side of a pipe by a constant is the same as multiplying or dividing the equivalent round size by the same constant. Thus, if the circular equivalent of an 80 x 24-in. duct is required, it will be twice that of a 40 x 12-in. duct, or 2 × 23.3 = 46.6 in.

A comprehensive study of equivalent duct sizes is to be made by the A.S.H.V.E. Research Laboratory in the near future for the purpose of determining whether Table 1 and Fig. 4 should be revised.

Elbow Friction Losses

It is customary to express the dynamic and friction losses in elbows as equal to a number of diameters of round pipe, or a number of widths of rectangular pipe, or equivalent length of duct [4]. The curves in Fig. 5 give the number of diameters or widths of pipe which have a frictional